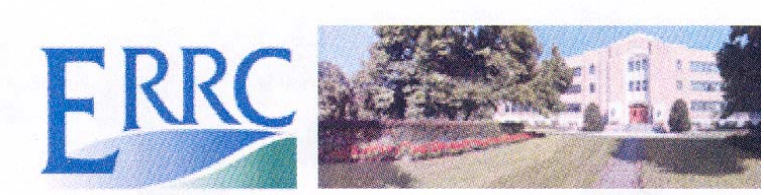

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Title: Sensorial, Nutritional and Microbiological Quality of Fresh Cilantro Leaves as Influenced by Ionizing Radiation and Storage

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Sensorial, nutritional and microbiological quality of fresh cilantro leaves as influenced by ionizing radiation and storage☆

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Abstract

The impact of gamma irradiation on aroma, appearance, nutritional, textural, and microbiological quality attributes of fresh cilantro (*Coriandrum sativum* L.) was investigated. Irradiation at doses up to 2 kGy did not significantly influence aroma, amount of total volatile compounds, color or overall visual quality. Although firmness of cilantro was reduced by irradiation at day 0, there was no significant difference among treatments after 3, 7 and 14 days of storage at 3 °C. Irradiation did not have a consistent effect on antioxidant power or phenolic content during the 14-day storage. In contrast, vitamin C content was lower at day 14 in samples irradiated at 2 and 3 kGy. Cilantro irradiated at 3 kGy had higher decay rate and off-odor scores than other samples after 14 days of storage. The total aerobic plate count of irradiated cilantro was significantly lower than that of nonirradiated controls immediately after irradiation and during the entire storage period. Our results suggest that fresh cilantro irradiated at 2 kGy retained its sensorial quality and shelf life.

Keywords: Cilantro; Irradiation; Quality; Nutrition; Storage; Microflora

1. Introduction

The fresh leaves of cilantro are widely featured in the cuisines of China, Mexico, South America, India and Southeast Asia. However, several recent outbreaks of illnesses have been implicated with consumption of the herb contaminated with foodborne pathogens (California Department of Health Services, 2000). In recent surveys of both domestic and imported produce, the US Food and Drug Administration has found that fresh cilantro has a high rate of pathogens (*Salmonella* and *Shigella*) (FDA, 1999, 2001). High rates of *Cryptosporidium oocysts*, a parasite, have also been found in cilantro (Monge & Chinchilla, 1996). Ionizing radiation is highly effective in inactivating foodborne pathogens and parasites in various foods (King & Josephson, 1982; Thayer, Josephson, Brynjolfsson, & Giddings, 1996), however, the effect of irradiation on the quality of cilantro is virtually unknown.

Quality characteristics of fresh herbs include an appearance of freshness, characteristic aroma and flavor, uniformity of color and size, and lack of defects such as decay and yellowing. Kinesthetic quality components such as the firmness or crispness of leafy tissues are also important if used in salads (Cantwell & Reid, 1993). The best postharvest conditions for cilantro are low temperature and high humidity storage in air (Loaiza & Cantwell, 1997). Under these conditions, a shelf-life of 14 days can be expected.

This study was conducted to investigate the impact of irradiation on flavor/aroma, appearance, nutritional, textural, and microbiological quality attributes of cilantro measured immediately after irradiation as well as during subsequent storage at 3 °C.

2. Materials and methods

2.1. Sample preparation

'Slobolt' cilantro (*Coriandrum sativum* L.) was harvested by uprooting the whole plant at a farm near

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Great Meadows, NJ. After harvest, the samples were transported on ice in insulated chests, and stored at 3 °C overnight before roots were cut and discarded. The leaves were then washed with cold tap water. Excess water was drained and yellow and senescent plants were discarded. The cilantro leaves were then packaged in zipper plastic bags perforated with two holes, 3 mm in diameter. The packages containing cilantro were randomly assigned to each treatment. There were seven packages (four for quality measurement and three for background microflora) per treatment/per storage time. Each package containing 50g of samples was regarded as a replicate. All preparation procedures were performed at 10 °C. After packaging, the cilantro leaves were stored at 3 °C overnight before being irradiated at 5 °C to doses of 0, 1, 2, and 3 kGy. The samples were then stored at 3 °C for 14 days. Quality was measured initially (immediately after irradiation), and 3, 7 and 14 days after irradiation.

2.2. Irradiation and dosimetry

The samples were irradiated using a self-contained cesium-137 gamma radiation source (Lockheed Georgia Co., Marietta, GA) with a dose rate of 0.098 kGy/min. The dose rate was established using alanine transfer dosimeters from the National Institute of Standards and Technology (Gaithersburg, MD). Variations in radiation dose absorption were minimized by placing the samples within a uniform area of the radiation field, by irradiating them within a polypropylene container (4-mm wall) to absorb Compton electrons, and by using the same geometry for sample irradiation during the entire study. During irradiation, temperature in the radiation chamber was maintained at 4 °C by flushing the gas phase of liquid nitrogen into the upper portion of chamber. To eliminate possible effects of nitrogen flushing during irradiation, all samples were placed in the chamber with nitrogen flushing for the same total period (approximately 31 min). Routine dosimetry was performed using 5 mm-diameter alanine pellets (Bruker Instruments Inc., Billerica, MA, USA). The pellets were placed into 1.2-ml cryogenic vials (Nalgene, Rochester, NY, USA), and the cryogenic vials were placed with the samples prior to irradiation. Absorbed doses were measured using a Brüker EMS 104 EPR analyzer and calculated in comparison with a standard curve.

2.3. Color measurement

A Hunter Miniscan XE colorimeter with a 26 mm measuring aperture (Hunter Associates Laboratory, Reston, VA, USA) was used to assess cilantro color. D65/10° was the illuminant/viewing geometry. Following calibration with the standard white and black plates, two readings were made on each package. Hue values were calculated from a^* and b^* values (McGuire, 1992).

2.4. Visual appearance

Each sample was visually rated by four judges according to systems developed by Loaiza and Cantwell (1997). For overall quality, the scale was 1–9 with 9 as excellent and 1 as unusable. Color was rated on a 5 to 1 scale, where 5 = dark green, fresh harvested, 4 = bright green, 3 = light green with yellowing or browning affecting 5% of leaf area, 2 = light green with noticeable yellowing or browning on 5–20% of leaf area, and 1 = light green with >20% of yellowing or browning. Typical aroma was evaluated after breaking the stems and was scored on a 5 (maximum) to 1 (none) scale. Off-odor was scored on 1 (none) to 5 (severe) scale while decay was evaluated by weighing decayed leaves and expressed as percentage of decay. Leaves that had brown or black discoloration were regarded as decayed.

2.5. Total volatile compounds

Samples (5g) were homogenized with 25ml saturated $CaCl_2$ using a homogenizer (Virtishear, Virtis, Gardiner, NY) at a speed setting of 70 for 1 min. The homogenates were then used for volatile extraction and separation using a solid phase microextraction technique and a Hewlett-Packard 5890/5971 GC-MSD (Agilent Technologies, Palo Alto, CA) equipped with an HP-5 trace analysis column (30 m×0.32 mm i.d., 0.25 μm film thickness). Individual volatile compounds were identified by comparison of spectra of the sample compounds with those of standards and with those contained in the Wiley–NBS library as well as by comparing retention times of sample compounds with those of the standards (Fan & Sokorai, 2002b). The amounts of individual compounds were calculated from standard curves. The amount of total volatile compounds was the sum of 13 identified major compounds.

2.6. Electronic nose

An AromaScan A32S/50SP system (AromaScan Inc., Hollis, NH) comprised sensor unit with 32-element sensor array of conducting polymers and a 50-vial autosampler was used in this study. Five milliliters of homogenates used for volatile analysis was added into 22-ml vials, which were then loaded onto the autosampler. There were eight vials for each dose (two vials for each replicate). Platen temperature was maintained at 40°C, and platen equilibrium time was 5 min. Sample equilibrium time was 15 min. Mix time was 1 min with mix power setting of 3. Transfer line temperature was set at 70 °C while sample loop temperature was maintained at 55 °C. Reference humidity was 40%. Both sampling time and data collection time were set to 5 min. Wash source was deionized water with wash time of 5 min. Information was collected every second. Data were

analyzed using the statistical software included with the instrument.

2.7. Texture analysis

Texture was determined using the TA.XT2i Texture Analyzer (Texture Technology Corp, Scarsdale, NY, USA) and a Kramer shear press with 5-blades. A 15-g random sample consisting both leaves and stems was placed into the press holder, and then the 5-blade plunger moved down at 2mm/s, to 1 cm below the bottom of the holder. Maximum force was recorded using the Texture Expert software (version 1.22, Texture Technology Corp, Scarsdale, NY, USA). Two readings were made on cilantro samples from each package. There was a total of eight measurements for each treatment.

2.8. Measurement of antioxidant power

Samples (5g) were homogenized with 20ml 50% ethanol using a homogenizer (Virtishear, Virtis, Gardiner, NY) at a speed setting of 70 for 2 min. The homogenate was filtered through four-layer cheesecloth and then centrifuged at 11,952 *g* for 10 min at 5 °C in a Sorvall RC2-B refrigerated centrifuge (Kendro Laboratory Products, Newtown, CT). Antioxidant power in the supernatants was determined using the ferric reducing antioxidant power (FRAP) assay (Benzie & Strain, 1996).

2.9. Phenolics analysis

Total phenolic content was measured using the Folin-Ciocalteu colorimetric method (Gao, Bjork, Trajkovski, & Uggla, 2000; Singleton, Orthofer, & Lamuela-Raventos, 1999). The same extract for FRAP assay was also used for phenolic analysis. The extract (0.9ml), mixed with 0.1 ml of 50 U/ml ascorbate oxidase, was incubated at 23°C for 90 min to remove ascorbic acid. Then the ascorbate-free extract (0.1ml) was mixed with 0.2ml of Folin-Ciocalteu reagent (Sigma Chemical Co., St Lois, MO). After incubation for 1 min at 23°C, 3ml of 5% Na_2CO_3 was added. Absorbances at 765nm were recorded for the mixtures after additional 2h incubation at 23°C. Phenolics were expressed as mg/g gallic acid equivalent.

2.10. Vitamin C analysis

Vitamin C (ascorbic acid plus dehydroascorbic acid) was measured according to Graham and Annette (1992) with minor modifications (Fan & Thayer, 2001).

2.11. Background microflora

Each sample consisted of a stomacher bag containing 50 g of irradiated cilantro. To each sample bag, 200 ml of sterile Butterfield's phosphate buffer (BPB) was added. The bag was closed and agitated (60s) to obtain a surface wash of the sample. A 1-ml aliquot was serially diluted in BPB in 1:10 increments to 10^5. Dilutions were pour plated with tryptic soy agar (TSA), three plates per dilution. Plates were inverted and incubated at 37 °C overnight. Plates were counted with an automated plate counter (AccuCount 1000, BioLogics, Gainesville, VA, USA). The experiment was performed three times, in replications run concurrently. The data from the three replications was pooled ($n = 9$).

2.12. Statistical analysis

There were four replicates for all measurements except three replicates for microflora measurement. Data were subjected to statistical analysis using SAS ver. 6.12 (SAS Institute, Raleigh, NC, USA). The effect of radiation dose and storage time as well as interaction between dose and storage time was performed using the GLM procedure. Regression effect of radiation dose and storage time was analyzed using orthogonal comparisons, and significance of polynomials was calculated using the Contrast statement of the GLM procedure.

3. Results and discussion

Instrumental color analysis indicated that hue values were not affected by irradiation at any dose during the entire storage period (Table 1). However, hue values of all samples decreased linearly during storage. Hue is the visually perceived color. In this study, the decrease in hue values indicates that cilantro leaves turned yellow during storage.

Visual color evaluation also suggested a progressive yellowing of cilantro during storage (Table 2). Irradiation at any dose had no effect on visual color evaluated immediately after irradiation or after 3 days of storage. However, samples irradiated to a dose of 3 kGy were visually more yellow than the non-irradiated samples at day 7 and 14.

The overall visual quality of both irradiated and non-irradiated samples deteriorated during storage (Table 3). Irradiation had no effect on overall quality at 0 and 3 days. But cilantro irradiated at 3 kGy had poorer overall visual quality than non-irradiated samples at 7 and 14 days.

Typical aroma (data not shown) and off-odor (Table 4) were not affected by irradiation at day 0 or 3. Samples irradiated at 3 kGy had less typical aroma and more off-odor scores than the non-irradiated sample at day 7 and 14. The intensity of off-odor increased and typical aroma progressively decreased during storage.

There was little decay developed within 7 days of storage. After 14 days of storage, decay was observed in all samples. Samples irradiated at 3 kGy had a significantly

Table 1
Hue values of irradiated and non-irradiated cilantro leaves during storage at 3 °C

Radiation dose (kGy)	Storage time (day)				$LSD_{0.05}$[a]	Linear	Quadratic	Cubic
	0	3	7	14				
0	115.8	115.5	115.3	113.9	1.8	*	NS[b]	NS
1	116.0	115.6	114.7	113.2	1.4	***	NS	NS
2	116.0	115.8	114.2	114.1	1.7	*	NS	NS
3	115.2	115.9	114.3	112.5	1.5	***	NS	NS
$LSD_{0.05}$[a]	1.8	1.6	1.5	1.6				
Linear	NS	NS	NS	NS				
Quadratic	NS	NS	NS	NS				
Cubic	NS	NS	NS	NS				

Cilantro leaves were irradiated with 0, 1, 2, or 3 kGy gamma radiation at 4 °C and then stored at 3 °C. Color was measured at 0, 3, 7 and 14 days after irradiation. The values are means of four replicates.
[a] The least significant difference at $P<0.05$.
[b] NS, nonsignificant.
* $P<0.05$.
*** $P<0.001$.

Table 2
Visual color (1–5) of irradiated and non-irradiated cilantro leaves during storage at 3 °C

Radiation dose (kGy)	Storage time (day)				$LSD_{0.05}$[a]	Linear	Quadratic	Cubic
	0	3	7	14				
0	4.8	4.4	4.3	3.9	0.4	***	NS[b]	NS
1	5.0	4.3	4.0	3.8	0.4	***	*	NS
2	5.0	4.3	3.8	3.8	0.3	***	**	NS
3	4.8	4.3	3.3	3.1	0.4	***	**	*
$LSD_{0.05}$[a]	0.3	0.5	0.3	0.2				
Linear	NS	NS	***	***				
Quadratic	NS	NS	NS	*				
Cubic	NS	NS	NS	NS				

Cilantro leaves were irradiated with 0, 1, 2, or 3 kGy gamma radiation at 4 °C and then stored at 3 °C. Visual color was evaluated at 0, 3, 7 and 14 days after irradiation. The values are means of four replicates
* $P<0.05$.
** $P<0.01$.
*** $P<0.001$.
[a] The least significant difference at $P<0.05$.
[b] NS nonsignificant.

Table 3
Overall visual quality (9–1) of irradiated and non-irradiated cilantro leaves during storage at 3 °C

Radiation dose (kGy)	Storage time (day)				$LSD_{0.05}$[a]	Linear	Quadratic	Cubic
	0	3	7	14				
0	9.0	8.6	7.7	6.6	0.4	***	NS[b]	NS
1	9.0	8.3	7.8	7.2	0.2	***	**	NS
2	8.9	8.2	6.9	7.0	0.6	***	**	NS
3	9.0	8.3	6.3	5.6	0.3	***	**	**
$LSD_{0.05}$[a]	0.2	0.5	0.6	0.4				
Linear	NS	NS	***	**				
Quadratic	NS	NS	NS	***				
Cubic	NS	NS	NS	NS				

Cilantro leaves were irradiated with 0, 1, 2, or 3 kGy gamma radiation at 4 °C and then stored at 3 °C. Visual quality was evaluated at 0, 3, 7 and 14 days after irradiation. The values are means of four replicates.
[a] The least significant difference at $P<0.05$.
[b] NS nonsignificant.
** $P<0.01$.
*** $P<0.001$.

Table 4
Off-odor (1–5) of irradiated and non-irradiated cilantro leaves during storage at 3 °C

Radiation dose (kGy)	Storage time (day)				$LSD_{0.05}$[a]	Linear	Quadratic	Cubic
	0	3	7	14				
0	1.0	1.0	1.2	1.8	0.2	***	*	NS[b]
1	1.0	1.1	1.3	1.6	0.2	***	NS	NS
2	1.0	1.0	1.6	1.8	0.2	***	NS	*
3	1.0	1.1	1.9	2.0	0.3	***	*	*
$LSD_{0.05}$[a]	–	0.1	0.3	0.2				
Linear	–	NS	**	*				
Quadratic	–	NS	NS	*				
Cubic		NS	NS	NS				

Cilantro leaves were irradiated with 0, 1, 2, or 3 kGy gamma radiation at 4 °C and then stored at 3 °C. Off-odor was evaluated at 0, 3, 7 and 14 days after irradiation. The values are means of four replicates.
[a] The least significant difference at $P<0.05$.
[b] NS nonsignificant.
* $P<0.05$.
** $P<0.01$.
*** $P<0.001$.

higher decay rate (15.2%) than non-irradiated cilantro (7.0%), and those irradiated at 1 (6.3%) and 2 kGy (7.1%). There was no significant difference ($P<0.05$) in decay among non-irradiated and those irradiated at 1 and 2 kGy.

The amount of total volatile compounds decreased linearly during storage (Table 5). After 14 days storage, total volatile compounds were less than half of initial amounts. Irradiation at any dose did not have a consistent effect on the amount of total volatile compounds. At day 14, the amount of volatiles tended to be lower with increasing radiation dose although the amounts were not significantly ($P<0.05$) affected by irradiation. Analysis of aroma using the AromaScan electronic nose did not reveal any irradiation-induced effect either (data not shown).

Although irradiation at doses up to 3 kGy did not affect amount of total volatile compounds, sensorial evaluation did reveal that samples irradiated at 3 kGy had an atypical aroma and off-odor. The off-odor may be related to higher decay rates observed on the 3 kGy samples. The volatiles measured with the GC–MS were the major compounds responsible for the characteristic aroma of fresh cilantro. The volatiles were mainly C_6–C_{13} unsaturated aldehydes, and did not include compounds possible from decayed leaves.

Firmness of cilantro decreased linearly with higher radiation doses at day 0 and day 7 (Table 6). The rate of firmness loss at day 0 was 10% per kGy calculated by the linear curve of firmness vs. dose. Firmness of all cilantro samples also decreased linearly during storage. After 14 days of storage, there was no significant difference in

Table 5
Amount of total volatile compounds (μg/g) of irradiated and non-irradiated cilantro leaves during storage at 3 °C

Radiation dose (kGy)	Storage time (day)				$LSD_{0.05}$[a]	Linear	Quadratic	Cubic
	0	3	7	14				
0	190.7	198.7	68.0	82.3	35.9	***	**	**
1	171.0	198.0	114.4	70.2	50.3	***	NS[b]	*
2	175.5	225.3	105.7	61.1	49.8	***	NS	**
3	173.3	159.5	73.5	58.1	43.7	***	NS	NS
$LSD_{0.05}$[a]	44.8	54.3	39.2	41.5				
Linear	NS	NS	NS	NS				
Quadratic	NS	NS	**	NS				
Cubic	NS	NS	NS	NS				

Cilantro leaves were irradiated with 0, 1, 2, or 3 kGy gamma radiation at 4 °C and then stored at 3 °C. Volatile compounds were measured at 0, 3, 7 and 14 days after irradiation. The values are means of four replicates.
[a] The least significant difference at $P<0.05$.
[b] NS nonsignificant.
* $P<0.05$.
** $P<0.01$.
*** $P<0.01$.

Table 6
Firmness (kg) of irradiated and non-irradiated cilantro leaves during storage at 3 °C

Radiation dose (kGy)	Storage time (day)				$LSD_{0.05}$[a]	Linear	Quadratic	Cubic
	0	3	7	14				
0	43.8	29.2	31.0	25.0	4.6	***	*	**
1	33.5	29.4	26.1	23.7	4.7	***	NS[b]	NS
2	30.3	25.5	24.2	22.7	4.4	**	NS	NS
3	30.2	25.9	25.5	23.7	6.0	*	NS	NS
$LSD_{0.05}$[a]	5.3	4.6	5.7	5.4				
Linear	***	NS	*	NS				
Quadratic	*	NS	NS	NS				
Cubic	NS	NS	NS	NS				

Cilantro leaves were irradiated with 0, 1, 2, or 3 kGy gamma radiation at 4 °C and then stored at 3 °C. Firmness was measured at 0, 3, 7 and 14 days after irradiation. The values are means of four replicates.
[a] The least significant difference at $P<0.05$.
[b] NS nonsignificant.
* $P<0.05$.
** $P<0.01$.
*** $P<0.001$.

Table 7
Antioxidant power (μmol/g) of irradiated and non-irradiated cilantro leaves during storage at 3 °C

Radiation dose (kGy)	Storage time (day)				$LSD_{0.05}$[a]	Linear	Quadratic	Cubic
	0	3	7	14				
0	14.8	13.0	16.2	16.2	3.4	NS[b]	NS	NS
1	17.7	14.1	16.8	19.7	3.8	NS	NS	NS
2	15.3	17.8	17.8	13.8	3.6	NS	*	NS
3	16.7	18.9	17.5	16.9	4.4	NS	NS	NS
$LSD_{0.05}$[a]	4.0	4.3	3.9	2.8				
Linear	NS	**	NS	NS				
Quadratic	NS	NS	NS	NS				
Cubic	NS	NS	NS	NS				

Cilantro leaves were irradiated with 0, 1, 2, or 3 kGy gamma radiation at 4 °C and then stored at 3 °C. Antioxidant content was measured using the ferric reducing antioxidant power assay at 0, 3, 7 and 14 days after irradiation. The values are means of four replicates.
[a] The least significant difference at $P<0.05$.
[b] NS nonsignificant.
* $P<0.05$.
** $P<0.01$.

Table 8
Vitamin C (μg/g fresh wt) of irradiated and non-irradiated cilantro leaves during storage at 3 °C

Radiation dose (kGy)	Storage time (day)				$LSD_{0.05}$[a]	Linear	Quadratic	Cubic
	0	3	7	14				
0	949	767	668	599	223	**	NS[b]	NS
1	826	660	723	535	170	**	NS	NS
2	831	728	591	301	224	***	NS	NS
3	829	779	723	268	235	***	NS	NS
$LSD_{0.05}$[a]	331	177	152	143				
Linear	NS	NS	NS	***				
Quadratic	NS	NS	NS	NS				
Cubic	NS	NS	NS	NS				

Cilantro leaves were irradiated with 0, 1, 2, or 3 kGy gamma radiation at 4 °C and then stored at 3 °C. Vitamin C was measured at 0, 3, 7 and 14 days after irradiation. The values are means of four replicates.
[a] The least significant difference at $P<0.05$.
[b] NS nonsignificant.
** $P<0.01$.
*** $P<0.001$.

firmness among the irradiated and non-irradiated samples. These results indicate that the loss of firmness in irradiated samples during storage was less than that of non-irradiated ones. During the 14 days of storage, the loss of firmness for samples irradiated at 0, 1, 2, and 3 kGy were 43, 30, 25, and 22%, respectively, compared with day 0 samples.

Antioxidant power (Table 7) and phenolic content (data not shown) had very similar response to irradiation and storage. There was little change during the 14 days of storage for both antioxidant power and phenolic content. Irradiation had no effect on antioxidant power or phenolic content except that irradiation increased antioxidant and phenolic content at day 7. Antioxidant power and phenolic content increased with higher radiation doses. The increased antioxidant power has also been observed in other vegetables (Fan & Sokorai, 2002a; Fan & Thayer, 2001) and fruits (Oufedjikh, Mahrouz, Amiot, & Lacroix, 2000). Phenolics are the major component of antioxidant activity in vegetables (Cao, Sofic, & Prior, 1996), therefore it is not unexpected that antioxidant and phenolics have similar responses to irradiation and storage.

Vitamin C content of all samples decreased during storage (Table 8). Irradiation had no effect on vitamin C content at day 0, 3 or 7. However, after 14 days of storage, samples irradiated at 2 and 3 kGy had lower vitamin C content than the non-irradiated samples. Vitamin C content and antioxidant power were more than 10 times higher than those observed in lettuce and alfalfa sprouts (Fan & Sokorai, 2002a; Fan & Thayer, 2001).

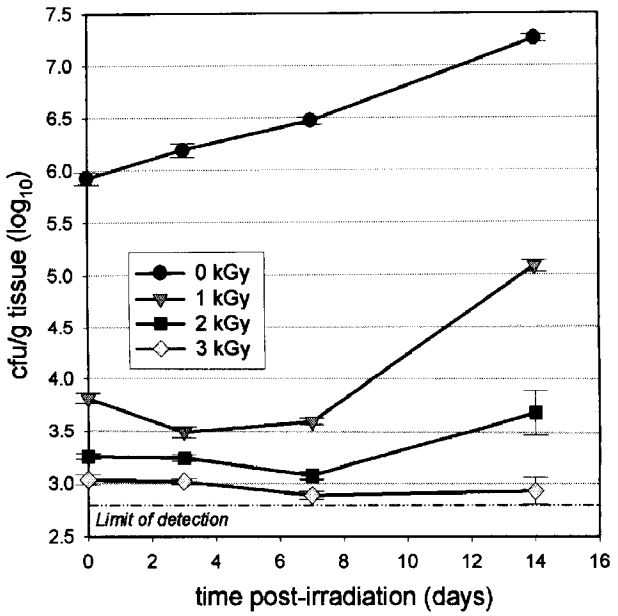

Fig. 1. Total aerobic plate count (TAPC) of the cilantro leaves during storage at 3 °C. Cilantro leaves were irradiated with 0, 1, 2, or 3 kGy gamma radiation at 4 °C and then stored at 3 °C. All data points represent means from three analyses accompanied by standard error bars.

The initial total aerobic plate count (TAPC) on the cilantro leaves was 5.9 cfu/g tissue (Fig. 1). TAPC on non-irradiated cilantro increased during the 14 days of storage, ultimately reaching 7.2 log cfu/g. Irradiation initially reduced the TAPC on cilantro for all doses, and bacterial growth remained suppressed for the first 7 days of storage. During the period of day 7 to day 14, TAPC rebounded in a dose-dependant manner. Cilantro which had received 1 kGy showed an increase of 1.4 log cfu/g, while the increase was only 0.6 log cfu/g following 2 kGy. Cilantro which had received 3 kGy showed no recovery of TAPC for the duration of the storage period. These results were in agreement with earlier observations in carrots (Chervin & Boisseau, 1994; Hagenmaier & Baker, 1998), lettuce (Prakash, Guner, Caporaso, & Foley, 2000), and other vegetables (Farkas, Saray, Mohacsi-Farkas, Horti, & Andrassy, 1997; Langerak, 1978).

The most important quality attributes to herbs are visual quality and aroma (Cantwell & Reid, 1993). Irradiation at doses up to 2 kGy did not cause any change on these quality attributes of fresh cilantro. Although samples irradiated at 2 kGy had lower vitamin C content than non-irradiated ones after day 14, cilantro, as an herb, does not contribute significantly to vitamin C intakes in human diets. Samples irradiated at 3 kGy had higher decay and lower visual quality scores after 14 days of storage.

Our results show decay rate increased with higher radiation dose and 3 kGy samples had a significantly higher decay rate than other treatments. In the present study, the decay was defined as black or brown discoloration of leaves. The high decay rate in the 3 kGy samples was most likely due to radiation injury. High doses of radiation may induce functional impairment to the cellular membrane systems, leading to loss of normal physiological processes, resulting in the death of cells and discoloration of tissues. Our results also suggest that the growth of bacterial micorflora was completely inhibited by irradiation at 3 kGy throughout the 14-day storage period. The decay observed in the 3 kGy samples may partially be results of growth of fungi. Fungi are much more resistant to irradiation than bacteria (El-Samahy, Youssef, Askar, & Swailam, 2000; Moy, 1983). Irradiation induces cellular leakage, resulting in availability of nutrients for surviving fungi to grow. The elimination of competing normal mircoflora by irradiation may also contribute to the growth of fungi during storage at 3 °C.

Langerak (1978) showed that radiation at 1 kGy resulted in reductions of bacterial populations while doubling the shelf life of cut endive. Farkas et al. (1997) showed that 1 kGy radiation reduced loads of spoilage bacteria, improved microbiological shelf life and extended sensorial keeping quality of pre-cut peppers and carrots. Prakash, Guner et al. (2000a) found that a dose of 0.35 kGy gamma radiation decreased aerobic counts by 1.5 logs on cut romaine lettuce. A 10% loss in firmness of lettuce was observed by the radiation dose while no other sensory attributes were affected. Prakash, Inthajak, Huibregtse, Caporaso, and Foley (2000) also found that 1.0 kGy radiation eliminated *Listeria monocytogenes* and *E. coli* inoculated on diced celery while extending shelf life by 1 week. Our results show that 2 kGy radiation significantly reduced bacterial populations of fresh cilantro without loss in quality. Samples irradiated at 3 kGy had deteriorated sensorial quality, higher decay and developed off-flavor compared to non-irradiated samples although 3 kGy samples had the lowest microfloral populations throughout the entire storage period.

In summary, our results indicate that doses up to 2 kGy did not significantly influence overall visual quality, decay, color, texture, nutritional values, aroma or amount of the volatile compounds of fresh cilantro and reduced microfloral loads. At a dose of 3 kGy, cilantro had more decay and deteriorated visual quality, as well as lower vitamin C content. Fresh cilantro leaves can therefore be expected to tolerate up to 2 kGy without any deterioration in quality attributes. At these doses, foodborne pathogens often observed on fresh cilantro, such as *Shigella* and *salmonella* may be inactivated.

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